

Fuzzy logic-based MPPT control for solar PV fed three-phase induction motor drive in water pumping applications

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ABSTRACT

The reliance on traditional energy sources for the agricultural water pumping framework leads to higher operational costs and environmental concerns. The partial shadings severely reduce the solar photovoltaic based water pumping framework efficacy. Owing to partial shading conditions, the output power of the photovoltaic array degrades, which reduces the water pumping output. Therefore, this article presents a low-cost solar photovoltaic fed three phase induction motor driven system, which helps for the rural water pump application. Here, maximum power point tracking of solar photovoltaic panel is done by fuzzy logic. Usually, the solar panel gives direct current power is stored in recharging battery and then setups and acts as source for voltage source inverter in the standalone model. A novel single step battery-low power transformation is used by developing a fuzzy maximum power track with buck-boost chopper that makes the total setup cost to reduced significantly. Mamdani fuzzy system is selected for maximum power point tracking (MPPT) controller because it has more intuitive and easier to understand If-Then rule bases. The suggested method is worked as a model having photovoltaic array, maximum power tracking with the buck-boost chopper, voltage source inverter, and three phase induction motor drive. The inverter is used sinusoidal pulse width modulation as the control algorithm. To check the simulation results the total set up is carried out in MATLAB software. The test results observed that the proposed prototype is useful. It's efficacy i.e., 75% with in response time (1 sec) for different insulations and temperatures.

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1. INTRODUCTION

The agriculture sector of India is deeply based on monsoon for usual irrigations. The pumping system is employed as the artificial scheme mean to give water for the irrigation. The Indian farmers dependent on the grid power or the diesel generator to work the pumping system that may lead to massive delay and financial stress. Therefore, an efficient irrigation prototype i.e., the solar photovoltaic water pumping is a better advantage. It enhances its crop yields by ensuring the reliable and persistent water supply to its field. The photovoltaic system transforms solar power to start the pump model, thus substituting inconsistent power grid and the pollution cause diesel power version. Diesel price is volatile and usually expensive, growing irrigation costs. Engines need frequent servicing, oil fluctuations, and spare components. Diesel pump will produce CO₂ and the particulate matter, cause air pollution and climate changes. Diesel engine gives substantial noise, affecting local community. Farmers in remote places face trouble in transporting fuel frequently. This system is solar power by the solar system which gives ground water for the irrigation. A large number of researches

have been done with solar systems [1]-[3]. The solar photovoltaic water pump prototype is performed with a photovoltaic panel capability in the range of 300 watts maximum value to 6000 watts maximum value. Necessary module number in parallel and series is applied to get the essential photovoltaic panel output. Each photovoltaic module power output is taken in photovoltaic arrays must be least of 75 watts amplitude value, with satisfactory establishment for power measurement tolerance. Photovoltaic module usage with high power outputs is preferable. Locally manufactured photovoltaic module having multi or mono solar crystalline silicon cell is applied in the photovoltaic arrays for the solar photovoltaic water pump system. The solar photovoltaic system with buck boost converter is addressed in [4], [5]. The DC-DC converter designing is explained in [6]-[9].

The three phase induction motor does not need electrical connections between motor rotating stationary parts. Thus, it does not require any commutators that it is maintenance free motor. Induction motor has higher overload capacity low inertia, low weight, and higher efficiency. Then, it is cheap and more robust motor, and lesser prove to any failures at higher speed. The changing frequency is need as the rotor part speed based on rotatory magnetic field the speed given by motor stator. The adjustable voltage is compulsory as induction motor resistance decreases at lower frequency and therefore currents have to be restricted by decreasing supply voltage. Induction motor is existing with greater than three phase-stator winding to permit a modification of the pole pair number. Three phase induction motor pumps normally available in market [10], [11]. This technology neither rely on the diesel nor on electricity, therefore individuals at remote location is avail the advantage solar pumping and increase its cropping zone with systematic water source through the solar pumping.

Grid unreliability hampers agricultural productivity, making solar-powered systems a viable alternative. The solar pump is free from issues like the feeder damages, electric supply cuts, and rate hike. The solar systems have been noted that owing to fluctuations of regular voltage most of induction motors burning out and the maximum time at facility centres. Nevertheless, solar system produces better quality and constant power which improves pump life of up to 30 years. Another motor need high amount torque that is worked by electrical supply, then novel solar system does not need and only disturbs rotor part that improves pump life, while other type of electrical running pump life become very low and cannot provide half of its solar pumping discharge. The maximum power tracking with different methods is addressed in [12]-[15]. The fuzzy logic system design is in the literature is very clearly presented in [16]-[18]. The maximum power tracking using fuzzy in solar system are investigated in [19]-[21].

It is operated on energy produced employing the photovoltaic solar system array [22]-[25]. It transforms solar power into electrical power that is taken for induction motor pumping set. It is drawing water from ponds, open wells, bore wells, streams, and canals. It needs also shadow-free zone for the photovoltaic array installation. Without solar photovoltaic water pump, most of groups in designing country require dependent on rainfalls and unreachable the water source. The reliable water is lacking limit collecting to just thrice the year. Most of the formers are forced to get its energy from the unclean, toxic fuel which harms community and environmental members. People need to dependent on the labour-intensive rope and bucket or exclusive petrol and diesel water pump system for irrigation its crop. Basically, solar power water pump running by changing the sun light to electrical power which will work water pumping. Then, it employs solar panel to gather the photon from the sunlight, making the DC power which creates the power for induction motor to the pumping water from the source. The voltage source inverter is applied if pumping model requires alternating current (AC) power rather than direct current (DC) power. The literature work prototypes are very complex, costly, and less efficiency. However, fuzzy maximum power tracking solar water pump system with buck-boost converter and three phase inverter needs to be explained which makes prototype more challenging.

The literature work prototypes are very complex, costly and less efficiency. However, fuzzy maximum power tracking solar water pump system with buck-boost converter and three phase inverter needs to be explained which makes prototype more challenging. Thus, buck-boost converter for solar power three phase induction motor driven motor for water pump using fuzzy control maximum power tracking is focused in this paper. It gives with enhanced performance, higher efficiency, low cost, and simplicity, the fed three phase induction motor driving is become the setup for pump and other irrigation applications in the remote place. This paper main contribution lies in the development and implementation of a fuzzy logic based maximum power point tracking algorithm for a solar photovoltaic system integrated with a water pumping drive application. While conventional tracking algorithms exhibit limitations under rapidly changing environmental conditions, including partial shading and dynamic irradiance variations. To overcome these challenges, the suggested work introduces an optimized fuzzy rules and membership functions tuning to ensure fast tracking speed, reduced oscillations around maximum power tracking, and enhanced overall efficiency compared to existing systems.

The rest of the section parts are organized as follows. Section 2 demonstrates the solar photovoltaic model and buck boost converter implementation and its fuzzy maximum power point tracking. Section 3 outlines induction motor and water pumping system. Section 4 explains simulation results of proposed system. Lastly, section 5 concludes the article with final remarking points.

2. PROPOSED SYSTEM

The suggested prototype main block diagram is given in Figure 1. The model exemplifies array, maximum power tracking with buck boost chopper, three phase voltage source inverter, a three-phase induction motor, and water pump. Total solar cells are linked in parallel and series to obtain required outputs as a sole solar cell is only provide a maximum voltage of 0.6 V to 0.8 V. This planned model is known as photovoltaic panels and are arranged in turn parallel and series to make photovoltaic arrays, as illustrated in Table 1. The solar photovoltaic cells have its own equivalent circuit diagram depicted in Figure 2. From the solar, a mathematical designed photovoltaic system is made in MATLAB simulation software. The inference system from mathematical model is the photovoltaic output is nonlinear characteristics in the nature and maximum power changes of sun light radiations and temperature. Figure 3 shows the photovoltaic system output characteristics. Its benefits lie in higher efficacy, simple design, and reduced components count. Nevertheless, it is not without limitations. The buck converter is a fundamentally step-down device, restricting its application to scenarios that need voltage reduction.

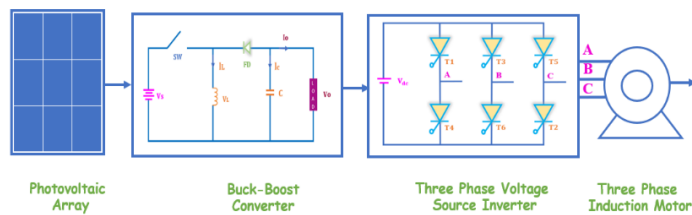


Figure 1. The suggested prototype main block diagram

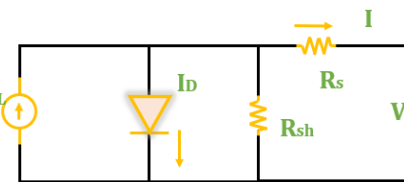


Figure 2. The equivalent circuit diagram of solar cell

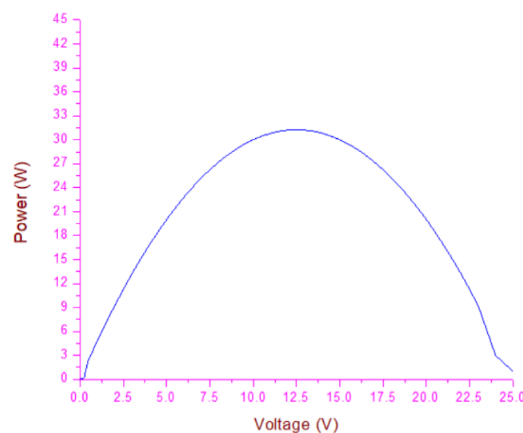


Figure 3. Power-voltage graph

Table 1. Solar panel electrical parameters

Parameter	Value
Maximum power	250.0 W
Voltage at maximum power (V)	30.05
Current at maximum power (A)	8.33
Open circuit voltage (V)	36.77
Short circuit current (A)	8.75

Solar side: Shading produces multiple power peaks on current-voltage curve; fastest cloud transients move the maximum power point quickly. Motor side: Rapid photo voltaic power swing cause DC link voltage dips, torque ripple, speed oscillations. Centrifugal pump is sensitive near shutoff; repeated stall and surge short life. Hydraulic side: Unsteady pressure is inducing water hammer and air ingress. DC motors have higher maintenance cost owing to motor brushes. The brushless DC (BLDC) motors have higher efficacy but complex controllers, costly, limited availability. Three-phase induction motors have reliable, rugged, low-cost, widely available, and best suited for medium-to-high power solar water pumping applications. Three phase induction

motors offer the best balance of ruggedness, reliability, cost, and availability, making it the most suitable for large term solar photovoltaic water pumping application. The BLDC motors are explored for small term, higher efficiency application, but cost is the limitation. The DC motors are not fit for long scale solar photovoltaic pumping owing to high maintenance and poor durability. The sinusoidal pulse width modulation is a generally used method for output voltage controlling and inverter frequency. It is employed primarily in conversion to generate sinusoidal waveform from a direct current source. The main idea is to control the of the inverter's switching signal pulse width.

3. FUZZY MAXIMUM POWER TRACKING CONTROLLER

The solar photovoltaic operating is to extract the maximum power from the photovoltaic module is known as maxim power tracking controller. It can able to work effectively in tracking and to give maximum from the solar panel, life span and efficacy of solar photovoltaic system is enhanced during all the conditions. It can be obtained by sinking the source of solar to load for numerous conditions to provide maximum power. The solar maximum power from the solar panels is extracted in two ways such as electrical and mechanical tracking. For the tracking of maximum power tracking during photovoltaic modules, an appropriate method is to be employed. It can be observer from the solar cell power and voltage graph diagram. Numerous approaches for tracking of solar maximum power are genetic algorithm, perturb and observe, incremental conductance, fuzzy, and faction open circuit voltage. In this research work, fuzzy method which has more benefits in most of the applications. The fuzzy maximum power tracking is demonstrated in Figure 4. Fuzzy maximum power tracking outperforms traditional schemes because it offers fast robustness, adaptability, and convergence without requiring exact photovoltaic systems. Nevertheless, tuning complexity, scalability, and hardware operation remain main challenges, especially for large scale and cost sensitive solar photovoltaic applications.

Fuzzy maximum power tracking is an adaptive technique, more intelligent that provides reduced oscillations, faster tracking, and better efficiency under dynamic conditions. It is used for maximizing the solar photovoltaic power output, particularly in environments with rapidly changing temperature solar and irradiance conditions. The fuzzy maximum power tracking system that makes intelligent decisions based on inputs in solar photovoltaic system. It has two input signals, one output signal and total 25 inference rules. The voltage (E) and power (P) are two inputs and D is duty cycle command that is transferred to buck-boost chopper is output. Furthermore, the fuzzy method is classified into fuzzifier, rule base, and defuzzifier. The main agenda of fuzzifier is convert from inputs and outputs to defined fuzzy values using membership functions. The input "E" membership functions (5) are E_NB, E_NS, E_ZE, E_PS and E_PB. The input "P" membership functions (5) are P_NB, P_NS, P_ZE, P_PS and P_PB. The input "D" membership functions (5) are D_NB, D_NS, D_ZE, D_PS and D_PB. The IF-THEN rules of system is shown in Figure 5. The most common de-fuzzing method is at present is center of area method is selected in this study. The fuzzy control maximum control has feature of strong robustness, fast tracking speed and good stability. The quality and efficacy of solar photovoltaic maximum power can be enhanced. The P-V graph study may lead to implement from the inference rules.

The fuzzy maximum power tracking controller continuously monitors photovoltaic voltage (E) and power (P). It computes ΔP and ΔE to determine if the system is moving towards or away from the maximum power tracking. Using if-then rules, it adjusts the buck-boost converter duty cycle (D). If maximum power point is not reached, D is decreased or increased. If maximum power point is reached, the D remains constant. The converter adjusts solar system output voltage accordingly. The enhanced DC power is given to the three-phase inverter, which powers the three-phase induction motor and water pump.

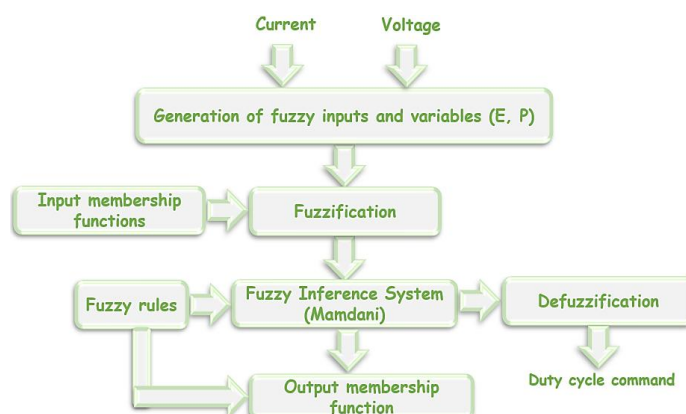


Figure 4. The fuzzy maximum power controller

1. If (E is E_PB) and (P is P_PB) then (D is D_PB) (1)
 2. If (E is E_PB) and (P is P_PS) then (D is D_PB) (1)
 3. If (E is E_PB) and (P is P_ZE) then (D is D_PB) (1)
 4. If (E is E_PB) and (P is E_NS) then (D is D_PS) (1)
 5. If (E is E_PB) and (P is P_NB) then (D is D_ZE) (1)
 6. If (E is E_PS) and (P is P_PS) then (D is D_PB) (1)
 7. If (E is E_PS) and (P is P_PB) then (D is D_PB) (1)
 8. If (E is E_PS) and (P is P_ZE) then (D is D_PS) (1)
 9. If (E is E_PS) and (P is E_NS) then (D is D_ZE) (1)
 10. If (E is E_PS) and (P is P_NB) then (D is D_NS) (1)
 11. If (E is E_ZE) and (P is P_PB) then (D is D_PB) (1)

If E is: E_NB, E_NS, E_ZE, **E_PS**, E_PB, none
 and P is: P_NB, E_NS, **P_ZE**, P_PB, P_PS, none
 Then D is: D_NB, D_NS, D_ZE, D_PB, **D_PS**, none

☐ not ☒ and ☐ or
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 Delete rule Add rule Change rule << >>

Renamed FIS to "Solar_Photovoltaic_MPPT" Help Close

Figure 5. Fuzzy rule system

4. INDUCTION MOTOR DRIVE

A voltage source inverter is a model which changes DC electrical power into AC electrical power at required output frequency and voltage. It is interfacing between any two electrical energy supplies: on one end DC system, and on other end the AC power grid. The transformation and feed in functions, the voltage source inverter is answerable for model controlling and performance system optimization. The modulation with sinusoidal pulse width is a main control approach in the inverter, owing to its advantages such as lower output voltage total harmonic distortion, lower switching loss, and high output voltages for equivalent DC-bus. This modulation with sinusoidal pulse width method includes digital waveform formation, the duty ratio is controlled which average output voltage shape corresponding to a pure sinusoidal waveform. A voltage source inverter setup is explained in MATLAB. The induction motors are widely applied in motor applications nowadays owing to the robustness, low cost, low maintenance, and reliability. Whereas pump water system for the irrigation purposes the load draws heavy currents then it is desirable to have solar panel that provide electrical power almost two to three times of induction motor rating. It recommends extracting the maximum electrical power from the solar system by employing the fuzzy maximum power tracking and yielding the solar for our pump water system purpose. Furthermore, the system needs the limited maintenance, meanwhile it operates without storage battery and it does not pollute environment in nature.

The only providing effective way varying induction motor system speed machine infinitely is to give supply the three phase induction motor with voltage of varying frequency and varying maximum value. The changing frequency is essential as the rotor speed based on revolving magnetic field speed given by stator part. The changing voltage is mandatory as induction motor impedance decreases at lower frequency and accordingly the currents have to be restricted by decreasing the main supply voltage. Formerly in power electronics, three phase induction motor speed control is limited is attained by the switching the three phase stator windings from the delta connections to the star connections, permitting the voltages at the induction motor winding to be decreased. The three phase induction motor is also existing with more than the three phase stator winding to allowing the pole pair number change. Though induction motor with numerous windings is additional expensive as additional than three phase networks to induction motor are required and only particular discrete speed is existing. The speed control of induction motor other alternative technique is realized by the slip ring rotor type induction motor type, where slip ring rotor winding sides are brought out to the slip rings.

5. EXPERIMENTAL RESULTS

The suggested fuzzy logic controller based maximum power tracking algorithm was executed on a solar photovoltaic system integrated with a buck-boost converter driving a water pumping load. The results were obtained using Simulink of MATLAB under fluctuating solar irradiance and temperature conditions. The scheme test simulations are performed in the MATLAB simulation software. It will realize maximum usage solar photovoltaic energy with buck boost chopper converter help. The solar photovoltaic optimization size through suggested buck boost converter copper decreases the cost, aside from improving the suggested system efficiency. The overall efficiencies proposed scheme at each 200 w/m² to 1100 w/m² are shown in Figure 6. The suggested scheme upholds 75% even low insulation level value. Photovoltaic panel (efficiency 20%, loss 80%), maximum power tracking (efficiency 95%, loss 5%), three phase inverter (efficiency 90%, loss 10%),

motor (efficiency 85%, loss 15%), water pump (efficiency 70%, loss 30%), environmental factors (efficiency 85%, loss 15%). It reflects the scheme superiority over other systems with conventional motor, DC motor, and BLDC motor. In order to validate the marketable developed scheme appropriateness and its capability to the other motor drives, the efficiency comparison of developed and other traditional arrangement is worked out. The simulation is explained several values of solar photovoltaic irradiance. The dynamic, transient, and steady state behavior of the suggested system are tested under rapid and slowly changing atmospheric conditions. The proposed scheme has manifested a fairly high efficacy at different standard environmental conditions. There are numerous advantages over other schemes. The comprehensive comparative study is tabulated in Table 2. The comparison study considering different parameters, efficiency, cost, and simplicity is presented. The suggested system appears better in every aspect as compare to other systems. Irrespective of operating conditions, it seems superior efficient than other schemes.

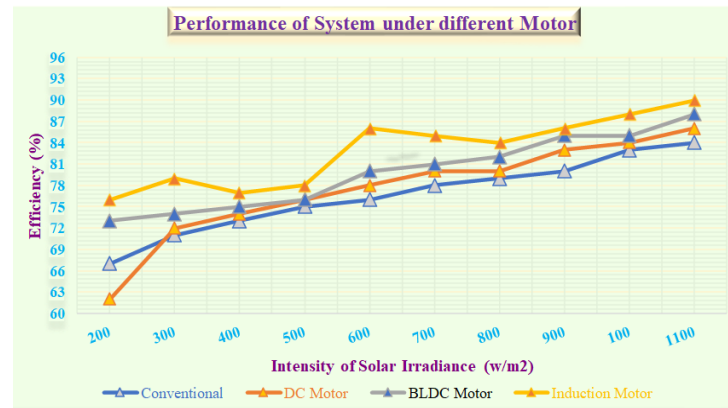


Figure 6. Experimental results of proposed system

Table 2. Comparison study

Ref	System	Response	Accuracy	Oscillations	Adaptability
[4]	Perturbation and observation method and incremental conductance method	Moderate	Moderate	High	Low
[5]	Conventional	Low	Low	High	Low
[15]	Artificial neural networks	Low	Low	High	High
[11]	Arduino fuzzy maximum power tracking	Moderate	Moderate	Moderate	Moderate
Proposed system	Fuzzy maximum power tracking	Fast	Very high	Low	High

6. CONCLUSION

The implementation and design of the solar photovoltaic fed three phase induction motor drive water pump system focused under the dynamic and static response in numerous practical running conditions. The MATLAB simulation employed for the proposed model simulation. Solar photovoltaic maximum power tracking is operated for buck boost converter using fuzzy control. The suggested prototype delivers single stage working by neglecting conversion stages. The speed control and starting of induction motor pumping done without extra circuit. It is low cost, and simple as phase current sensor elimination. It has effective working even at different solar irradiances. The model is beneficial in the fish farms, the street water systems, and farm irrigations. It is capable of running the solar photovoltaic array at maximum power by employing voltage source inverter. The voltage source inverter is employed to drive three phase induction motor using taking into account utmost simpler and reliable control method. The suggested model works satisfactorily with changing temperatures and insolation. Meanwhile, it is given with enhanced performance, higher efficiency, low cost, and simplicity, the fed three phase induction motor driving is become the setup for pump and other irrigation applications in the remote place. We can develop the solar water pumping with three phase induction motor using other type of DC-DC converter in future. Future research work can move towards hybrid, AI-driven, and storage-integrated solar pumping frameworks that are scalable, cost-effective, and reliable for agricultural development applications.

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Arjyadhara Pradhan	✓		✓	✓				✓	✓	✓	✓	✓		
Babita Panda				✓		✓	✓			✓				✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo: Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AP], upon reasonable request.

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